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Preston, Tate; Wills, Alison

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1    **A single hydrotherapy session increases range of motion and stride length in**  
2    **Labrador Retrievers diagnosed with elbow dysplasia**

3    Tate Preston<sup>a</sup> and Alison P. Wills<sup>a\*</sup>

4    *<sup>a</sup>Department of Animal and Agriculture, University Centre Hartpury, Hartpury,*  
5    *Gloucester, Gloucestershire, United Kingdom GL19 3BE*

6    \* Corresponding author. Tel.: 01452702347.

7    *E-mail address: [Alison.Wills@Hartpury.ac.uk](mailto:Alison.Wills@Hartpury.ac.uk) (A.P. Wills).*

8

## 9     **Abstract**

10             Canine elbow dysplasia is a debilitating condition of unknown aetiology and  
11     is a common cause of forelimb lameness in dogs. Canine hydrotherapy is a  
12     therapeutic approach rapidly increasing in popularity for the treatment of range of  
13     musculoskeletal pathologies. In this study, kinematic analysis was used to assess the  
14     effect of a customised hydrotherapy session on the range of motion, stride length and  
15     stride frequency of healthy Labrador Retrievers (n=6) and Labrador Retrievers  
16     diagnosed with bilateral elbow dysplasia (n=6). Reflective kinematic markers were  
17     attached to bony anatomical landmarks and dogs were recorded walking at their  
18     preferred speed on a treadmill before and 10 minutes after a single hydrotherapy  
19     session. Range of motion, stride length and stride frequency were calculated for both  
20     forelimbs. Data were analysed via a robust mixed ANOVA to assess the effect of  
21     hydrotherapy on the kinematic parameters of both groups.

22             Range of motion was greater in the healthy dogs at baseline ( $p<0.05$ ).  
23     Hydrotherapy increased the range of motion of the forelimbs of both groups  
24     ( $p<0.05$ ); dogs with elbow dysplasia demonstrated a greater improvement in range of  
25     motion than healthy dogs ( $p<0.05$ ). Hydrotherapy stride length ( $p<0.01$ ) of all dogs,  
26     but differences were not seen between the two groups. Stride frequency increased  
27     after hydrotherapy only in the left limb ( $p<0.05$ ) in all dogs.

28             These results support the potential of canine hydrotherapy as a therapeutic  
29     tool for the rehabilitation and treatment of Labradors with elbow dysplasia.  
30     Furthermore, results indicate that hydrotherapy might improve the gait and  
31     movement of healthy dogs. However, whether these results are transient or sustained  
32     remains undetermined.

33    *Keywords:* Elbow dysplasia; dogs; hydrotherapy; kinematics; gait analysis

## 34     **Introduction**

35             Canine Elbow Dysplasia (ED) is a common developmental disorder  
36     affecting the canine cubital joint (Burton et al., 2008; Michelsen, 2013). Elbow  
37     dysplasia is a non-specific term encompassing several elbow pathologies, most  
38     commonly fragmented medial coronoid process, ununited anconeal process,  
39     osteochondrosis and osteochondritis dissecans of the medial humeral condyle,  
40     with some authors also including elbow incongruity and articular cartilage  
41     erosion (Kirberger and Fourie, 1998). Fragmented medial coronoid process,  
42     ununited anconeal process and osteochondritis dissecans can present singularly  
43     or in any combination (Kramer et al., 2006), and can occur concurrently in a  
44     single elbow (Fitzpatrick and Yeadon, 2009).

45             The epidemiology, pathogenesis, diagnosis and treatment of ED has been  
46     extensively investigated, but the aetiology eludes investigators (Gemmil et al.,  
47     2005). Elbow dysplasia can be extremely debilitating and cause lameness, but no  
48     current medical or surgical procedures alter the progression of the disorder or  
49     cure it (Kirberger and Fourie, 1998; Michelsen, 2013). Furthermore, the complex  
50     mode of inheritance and environmental variables in disease expression preclude  
51     genetic testing from providing a simple solution (Michelsen, 2013).

52             Elbow dysplasia is inherited as multifactorial polygenic traits, with the  
53     different manifestations appearing to be inherited independently (Kirberger and  
54     Fourie, 1998). Medium and large breed dogs tend to manifest signs most  
55     frequently (Meyer-Lindenberg et al., 2006), but ED has also been documented in  
56     Dachshunds and French Bulldogs (Narojek et al., 2008; Sjöström, 1998). The  
57     incidence of the different forms of the disease appears to be breed dependent,

58 with Rottweilers and Labradors often developing fragmented medial coronoid  
59 processes, German Shepherds having a high percentage of ununited anconeal  
60 processes (Morgan et al., 2000).

61 Diagnosing ED can be challenging for a number of reasons, particularly in  
62 dogs presenting with thoracic limb lameness (Houlton, 2009). Dogs present with  
63 varying degrees of lameness, which can be exacerbated with exercise (Kirberger  
64 and Fourie, 1998). Physical exam findings include pain, joint effusion, joint  
65 capsule thickening, muscle atrophy and osteoarthritis (Morgan et al., 2000).

66 Treatment for ED should ideally occur before osteoarthritis develops,  
67 however, this depends on early diagnosis of individual cases, with dogs  
68 displaying mild to moderate incongruity being good surgical candidates  
69 (Michelsen, 2013; Morgan et al., 2000; Palmer, 2011). Investigators have  
70 examined various surgical interventions for different forms of ED (Cook et al.,  
71 2008; Danielson et al., 2006; Fitzpatrick and Yeadon, 2009; Palmer, 2011;  
72 Preston et al., 2001; Turner et al., 1998), but a lack of controlled studies limits  
73 the interpretation of efficacy of these interventions (Michelsen, 2013).

74 Medial coronoid disease is the most common pathological presentation of  
75 ED, with Labradors often affected (Kirberger and Fourie, 1998). Studies to date  
76 have suggested arthroscopic fragment removal reduces morbidity in milder cases  
77 (Bouck et al., 1995; Evans et al., 2008; Meyer-Lindenberg et al., 2003; Palmer,  
78 2010). However, the only controlled prospective study comparing surgery with  
79 medical management of medial coronoid disease failed to demonstrate a benefit  
80 of surgery and indicated that dogs experience loss of function post-operatively  
81 (Burton et al., 2011). With conservative options only recommended in cases of

82 mild cartilage damage (Burton et al., 2011; Michelsen, 2013), regardless of  
83 whether dogs are surgically or medically managed, there is a clear requirement  
84 for alternative options such as hydrotherapy to be investigated for the  
85 rehabilitation of dogs with ED.

86         Hydrotherapy is a conservative approach to rehabilitation that may reduce  
87 pain and restore range of motion (ROM) in dogs suffering from ED, however,  
88 scientific research confirming the efficacy of hydrotherapy is limited (Houlding,  
89 2011). Therapeutic exercise is a key component of all rehabilitation programmes  
90 and is recommended as part of the concurrent care of any animal, albeit without  
91 clinical evidence of efficacy (Saunders, 2007). Buoyancy can help to encourage  
92 stiff joints into an improved ROM; consequently, hydrotherapy has been  
93 recommended for multiple musculoskeletal pathologies (Monk, 2007; Prankel,  
94 2008). Dogs subjected to swimming showed an increased ROM compared to  
95 those subjected to walking following surgery for cranial cruciate ligament rupture  
96 (Marsolais et al., 2003). Furthermore, dogs subjected to exercise on a water  
97 treadmill as part of a physiotherapy programme after cranial cruciate ligament  
98 rupture repair showed greater ROM compared to dogs that only participated in  
99 home exercise (Monk et al., 2006). Water treadmill exercise can be altered to  
100 best meet the requirement of individual animals, with variables such as water  
101 depth and treadmill speed resulting in altered gait parameters (Barnicoat and  
102 Wills, 2016; Millis and Levine, 2014). Because dogs with ED have decreased  
103 ROM after surgery, modalities such as hydrotherapy that facilitate an increase in  
104 elbow ROM could help conserve or restore ROM post-operatively (Barthélémy  
105 et al., 2014).

106           Therefore, we investigated the effect of a single session of hydrotherapy on  
107   elbow ROM and stride parameters when walking on a treadmill of both healthy  
108   dogs and dogs that had been diagnosed with ED. We hypothesised that dogs  
109   would have an increased ROM as a result of increased limb flexion (Monk et al.,  
110   2006) after undergoing a session of hydrotherapy.

## 111   **Materials and Methods**

112           Ethical approval for this study (ETHICS2015-05) was received from the  
113   University Centre Hartpury ethics committee on 20<sup>th</sup> November 2015 and work was  
114   conducted in line with institutional ethical guidelines.

### 115   *Experimental Population*

116           The study was conducted at Cheshire Canine Hydrotherapy centre, Cheshire,  
117   and Cotswold Dog Spa at Hartpury College, Gloucester, between November 2015  
118   and March 2016. All therapists involved had an ABC small animal hydrotherapy  
119   certificate. We examined six clinically sound Labradors (median age 2.0; range 1 to  
120   4) and six Labradors with bilateral elbow dysplasia (median age 5.5; range 2 to 6).  
121   Sexes were equally distributed, with three males and three females in each group.  
122   The sample size for the ED (n = 6) and control group (n = 6) was determined by the  
123   number of cases that fit the inclusion criteria and for which owner permission could  
124   be obtained that were referred to either of the two centres between November 2015  
125   and March 2016. We did not calculate an a priori sample size.

126           Each dog underwent a full veterinary examination prior to participating and  
127   owners were required to complete a consent form. Dogs with ED had been referred  
128   by their veterinarian for hydrotherapy. We recorded the referral details for these



129 dogs, including currently prescribed and previous medication (if any), type of elbow  
130 dysplasia and method of diagnosis (Table 1).

### 131 *Inclusion and Exclusion Criteria*

132 Inclusion criteria required participants to be Labradors with a non-specific  
133 diagnosis of bilateral elbow dysplasia obtained by diagnostic imaging. All dogs  
134 underwent diagnostic imaging (radiography and or computed tomography) prior to  
135 referral. Referring clinicians also assigned the specific pathologic diagnosis  
136 (osteochondritis dissecans, fragmented medial coronoid process or ununited anconeal  
137 process, Table 1). Exclusion criteria included Labradors that had previously  
138 undergone surgery on either elbow, Labradors with concurrent musculoskeletal  
139 pathologies or spinal disease, Labradors over the age of eight, and non-Labrador  
140 breeds. Dogs undergoing a multi-modal treatment plan including other therapies  
141 (physiotherapy, acupuncture etc.) were also excluded. The attending hydrotherapist  
142 determined prior to commencement of data collection whether dogs with elbow  
143 dysplasia were able to walk comfortably on the dry treadmill; dogs unable to walk  
144 comfortably were excluded for ethical reasons. Labradors in the control group had to  
145 be clinically sound adults of normal weight with no history of musculoskeletal or  
146 other disorders.

### 147 *Kinematic Markers*

148 Three reflective adhesive markers (diameter 18mm) were placed by the same  
149 investigator using double-sided adhesive tape on bony anatomical landmarks whilst  
150 the subject was weight bearing on all four limbs. The markers were positioned in  
151 accurately defined anatomical landmarks on the left forelimb and right forelimb: one

152 distal to the elbow joint, another near the rotation centre of the joint, and a third  
153 proximal to the joint.

#### 154 *Treadmill Protocol*

155 All dogs were recorded walking on a dry treadmill before and after they  
156 underwent a customised hydrotherapy session. The gait analysis was conducted  
157 approximately 10 minutes after the hydrotherapy session was completed. This time  
158 included drying the dog prior to beginning the treadmill protocol. The primary  
159 investigator and hydrotherapist were not blinded to whether dogs were control or  
160 experimental subjects. Experimental trials were recorded using an AZ1VR Action  
161 Cam HDR-AZ1 video camera (Sony) sampling at 60 frames per second. Each dog  
162 had its collar and lead removed and was fitted with a safety harness. Dogs were  
163 encouraged to move on to the treadmill using the harness and lead. The dogs were  
164 held on a leash by a handler positioned at the front of the treadmill and positioning of  
165 the head was kept as constant as possible using a food incentive in order to achieve a  
166 uniform gait. The treadmill was started at a low speed that was increased gradually  
167 until the dogs were walking at 1.2 m/s, however, if the dog could not walk  
168 comfortably at this pace, the speed was reduced to 1.0 m/s. This decision was  
169 determined by the acting hydrotherapist. Once the dog established a steady gait in  
170 walk the duration of recording was 120 seconds (Barnicoat and Wills, 2016). There  
171 was a short acclimatisation period which was subjectively determined by the  
172 hydrotherapist for each individual.

#### 173 *Hydrotherapy Protocol*

174 Hydrotherapy sessions all used the same therapeutic techniques in a pool  
175 specifically designed for canine hydrotherapy. The sessions included timed intervals

176 or laps in the water guided by a therapist with a focus on facilitating ROM in the  
177 elbow joint. All therapists recorded the protocol used in the session and each session  
178 lasted 20 minutes. All dogs were fitted with an appropriately sized safety harness to  
179 enable the hydrotherapist to control the direction of the dog whilst swimming  
180 (Prankel, 2008).

### 181 *Data Analysis*

182 Video recordings were analysed using Dartfish Analyser motion capture  
183 software (Dartfish). The ROM of the elbow (measured in degrees) was calculated by  
184 maximum extension minus maximum flexion of the right and left elbow joint. The  
185 extension and flexion was calculated for 40 strides for each limb before and after the  
186 hydrotherapy session. Therefore, a total of 160 strides were analysed for each  
187 subject.

### 188 *Stride Parameters*

189 Stride parameters including stride length (defined as the distance between  
190 two successive contacts of the same limb in metres, (m), stride time (s) and stride  
191 frequency (defined as the number of strides taken per unit time, Hz) were calculated  
192 for each limb for each subject. Mean stride length and mean stride frequency were  
193 calculated using 40 strides per limb before and after the hydrotherapy session.

### 194 *Statistical Analysis*

195 All statistical analyses were performed in R version 3.3.2; package WRS2 (R  
196 Core Team, 2016). Data were tested for normality and were found to be non-  
197 parametric. Therefore, robust bootstrapped two-way mixed ANOVAs were used to  
198 test for differences in ROM, stride length and stride frequency before and after the

199 hydrotherapy session and for differences between the healthy and elbow dysplasia  
200 groups. The condition of the dogs (healthy or ED) was the between groups variable  
201 and hydrotherapy (before or after) was the within groups variable. Stride length and  
202 stride frequency measured from the left and right forelimbs were analysed separately  
203 for both the healthy and elbow dysplasia groups due to potential differences between  
204 limbs in the dogs with bilateral pathology.

## 205 **Results**

206 All dogs successfully completed the experimental protocol and therefore a  
207 total of 960 strides from twelve dogs (six healthy, six elbow dysplasia) were taken  
208 forward for statistical analysis. Baseline kinematic characteristics and kinematic  
209 profiles for all subjects after hydrotherapy can be seen in Table 2.

### 210 *Range of Motion*

211 Healthy Labradors showed a greater ROM of the right and left elbows than  
212 Labradors with ED ( $\phi = 15.87$ ,  $p < 0.0001$  for right;  $\phi = 13.92$ ,  $p < 0.05$  for left; Fig. 1).

213 Healthy Labradors showed a greater ROM of right and left elbows ( $\phi = -7.35$ ,  
214  $p < 0.0001$  for right;  $\phi = -8.04$ ,  $p < 0.05$  for left) after the session. However, Labradors  
215 with ED increased the ROM of right and left elbows ( $\phi = 7.94$ ,  $p < 0.05$  for right;  $\phi =$   
216  $12.91$ ,  $p < 0.0001$  for left) more than healthy Labradors after the hydrotherapy session  
217 (Fig. 1).

### 218 *Stride Length*

219 Healthy Labradors had a longer right and left limb stride length ( $\phi = 0.02$ ,  
220  $p < 0.05$  for right;  $\phi = 0.03$ ,  $p < 0.05$  for left) than Labradors with ED at baseline.  
221 Hydrotherapy increased stride length of both limbs ( $\phi = -0.02$ ,  $p < 0.05$  for right;  $\phi = -$

0.02,  $p < 0.01$  for left) when all dogs were examined together. Labradors with and without ED did not differ in this increase in stride length attributed to hydrotherapy ( $\phi = -0.01$ ,  $p = 0.351$  for right;  $\phi = 0.01$ ,  $p = 0.136$  for left; Fig. 2).

### *Stride Frequency*

Stride frequency did not differ between healthy Labradors and Labradors with ED at baseline ( $\phi = -0.10$ ,  $p = 0.188$  for right;  $\phi = -0.05$ ,  $p = 0.549$  for left). Hydrotherapy did not alter stride frequency of the right limb ( $\phi = -0.03$ ,  $p = 0.090$ ), but increased stride frequency of the left limb ( $\phi = -0.05$ ,  $p < 0.0001$ ) when both groups were examined together. Labradors with and without ED did not differ in the change in stride frequency after hydrotherapy ( $\phi = 0.01$ ,  $p = 0.865$  for right;  $\phi = 0.02$ ,  $p = 0.261$  for left; Fig. 3).

## **Discussion**

We found that hydrotherapy improved ROM of the elbow in the left and right forelimb of healthy Labrador Retrievers, but improved ROM more in Labrador Retrievers with elbow dysplasia. Additionally hydrotherapy increased stride length in both groups to a similar extent, but did not affect stride frequency.

Swimming promotes an increased ROM, as has been demonstrated in studies assessing limb movement during aquatic exercise (Marsolais et al., 2003; Owen, 2006). This is similar to our observations. However, as our study did not examine gait during water treadmill exercise, data may not be directly comparable. Increased circulation to the forelimbs might reduce pain and allow muscle relaxation resulting in a freer gait (Kamioka et al., 2010). Healthy dogs increased elbow ROM similarly to dogs with ED, which may have implications for elite performance, where an increased ROM and, consequently, stride length, might facilitate increased top

246 speeds (Hudson et al., 2012). However, there is a possibility that the temperature of  
247 the water (30°C) could act as a type of thermotherapy which could improve muscle  
248 elasticity and joint extensibility (Wilcock et al., 2006). If so, this effect of increased  
249 ROM and stride length might be transient. Some researchers have proposed that the  
250 temperature of the water could have an analgesic effect which could also explain the  
251 increased ROM observed immediately after the session (King, 2016).

252         Our study corroborates previous work where swimming dogs showed  
253 increased joint ROM (Marsolais et al., 2003), and human studies that have reported  
254 increased biomechanical function after aquatic exercise (Denning, 2010; Kamioka et  
255 al., 2010). An improved ROM can assist in providing long-term analgesia in addition  
256 to improving the overall function of the limb (Canapp et al., 2009). A study  
257 investigating the use of hydrotherapy for post-operative rehabilitation of dogs has  
258 suggested that an improved ROM can reduce the chance of re-injury and facilitate a  
259 rapid return to function (Monk et al., 2006) However, Monk et al., (2006) only  
260 documented short-term improvements in ROM, so positive changes in ROM might  
261 not persist. Despite this, improving the function of the affected limbs should impact  
262 positively on the welfare of affected animals, enabling them to undertake normal  
263 locomotor activities with less pain. In addition to an overall ROM, changes in flexion  
264 and extension are also important, as maintaining ROM in dogs with ED can be  
265 difficult. This is particularly true post-surgery where decreased ROM has been  
266 documented in ED dogs (Barthélémy et al., 2014). Our study suggests that  
267 hydrotherapy might provide a valid means of maintaining elbow ROM in dogs that  
268 have undergone surgical procedures.

269         A single session of hydrotherapy increased the stride length of both control  
270 groups. This is consistent with the increase in ROM of the elbow joint that was also

271 observed in both groups, however, changes in flexion and extension of other joints  
272 might also have contributed to the increased SL observed. As has been previously  
273 reported in obese dogs, dogs with ED in our study had shorter stride length than  
274 healthy dogs (Brady et al., 2013). However, this differs from studies of dogs with hip  
275 dysplasia, where stride length was longer in affected dogs than healthy animals  
276 during over ground locomotion (Bennett et al., 1996). An increased stride length  
277 may be beneficial in performance dogs as increasing stride length along with changes  
278 in other gait parameters may enable dogs to reach higher speeds (Hudson et al.,  
279 2012). However, increasing speed is not a primary aim of therapy for pathological  
280 animals; rather, the longer stride length might represent return to a normal gait  
281 pattern.

282         Stride frequency was less affected by a session of hydrotherapy than the other  
283 gait parameters recorded. There was no difference in stride frequency between the  
284 two conditions and stride frequency was only increased by hydrotherapy for the left  
285 limbs. This finding is likely due to a chance finding because of individual variation  
286 in the small sample population, rather than a real effect – it would be difficult to  
287 explain this finding from a physiological perspective. An increased number of  
288 subjects would help to elucidate the effect of hydrotherapy on stride frequency.  
289 Previous research in dogs and horses has demonstrated that stride frequency  
290 decreases with increasing depth when walking on an underwater treadmill (Barnicoat  
291 and Wills, 2016; Scott et al., 2010). However, there has been limited research  
292 conducted in quadrupeds investigating the effect on stride frequency after a session  
293 of hydrotherapy has been completed. One study conducted in human patients with  
294 osteoarthritis concluded that there was no difference in stride frequency between

295 groups that had undergone underwater treadmill and land based exercise (Denning,  
296 2010).

297 Overall, our findings suggest that hydrotherapy represents a valid therapeutic  
298 intervention for Labradors with ED and that alterations in gait parameters are evident  
299 immediately after a session. However, further research is needed to investigate  
300 whether these effects persist and how this might affect the required frequency of  
301 hydrotherapy. This is the first study to investigate the effect of hydrotherapy on  
302 ROM of dogs with ED and, as such, we have nothing in the literature with which to  
303 compare or contrast our findings. Data gained from healthy animals in this study  
304 supports the previous understanding that hydrotherapy might benefit athletic dogs  
305 (Levine et al., 2004; Marcellin-Little et al., 2005). Whilst only Labradors were  
306 recruited in this study to attempt to control for breed variation in gait parameters, the  
307 sample size ( $n = 6$  per condition) was quite limited. Future research could utilise  
308 larger populations and assess a range of breeds, as different breeds are predisposed to  
309 the various clinical manifestations of the disease (Morgan et al., 2000). Due to the  
310 variation in the underlying pathophysiology between the different clinical  
311 presentations, these animals might respond differently to hydrotherapy. In this study,  
312 the passive ROM of the ED dogs was not measured with a goniometer prior to the  
313 commencement of the study, therefore the severity of the pathology was not  
314 quantified which may have introduced variability into the data. In addition, the  
315 control group were not age matched to the ED group and as such, they may have had  
316 early stage pathology that was not clinically diagnosed. It is suggested that future  
317 studies gain passive ROM data from pathological animals to provide a more detailed  
318 understanding of the severity of their lameness prior to them undergoing  
319 hydrotherapy.



320 As the effect of hydrotherapy seen in both the healthy and pathological  
321 animals could be attributed to a non-specific conditioning or training effect  
322 (Denning, 2010), it would have strengthened this work to have a control group of  
323 dogs with ED that did not undergo hydrotherapy. However, it would be difficult to  
324 attribute a conditioning or training effect to a single hydrotherapy session. We did  
325 not perform a sham treatment with ED dogs for ethical reasons, but [this](#) could be  
326 considered in future work, particularly if the sample population contained young  
327 animals with low grade ED. Alternatively, a control group that underwent a walking  
328 protocol could be utilised to help to determine whether the effect is attributable to  
329 hydrotherapy or just training in general.

330 This experiment utilised 2D as opposed to 3D kinematic analysis to assess  
331 gait parameters and research has suggested that this might result in a loss of accuracy  
332 (Miró et al., 2009). Conversely, many studies utilise 2D kinematic analysis to assess  
333 both angular and linear variables. Nevertheless, due to the pattern of dysplastic limbs  
334 being rotated inward with the elbows rotated outward there may have been an effect  
335 of hydrotherapy on mediolateral movement that was not assessed in this study  
336 (Morgan et al., 2000). As some small differences in movement have been detected  
337 between treadmill and overground locomotion in dogs, it is possible that the effects  
338 seen might differ slightly from terrestrial locomotion (Torres et al., 2013). This study  
339 allowed dogs a short period of acclimatisation to the treadmill prior to any data being  
340 collected, however, dogs did not undergo multiple habituation sessions over several  
341 days as has been suggested to ensure repeatability of stride parameters (Gustås et al.,  
342 2016, 2013).

343 We did not explore the effect of other common therapeutic modalities such as  
344 acupuncture and passive range of motion exercises on the ROM of dogs with ED.

345 Future work could explore whether these therapies represent a better option for dogs  
346 with ED than hydrotherapy, and could appraise the efficacy of a multi-modal  
347 approach.

## 348 **Conclusions**

349 It is possible to observe significant differences in kinematic parameters of  
350 Labradors with and without ED after a single session of hydrotherapy. These changes  
351 may be beneficial in the management of pathological animals and reiterates the  
352 current understanding that hydrotherapy is an appropriate therapeutic intervention for  
353 these animals. Further work is needed to explore whether these changes are still  
354 evident after the cessation of hydrotherapy.

## 355 **Conflict of Interest**

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501 Table 1. Referral information for dogs with elbow dysplasia

Participant and subject number	Participant Age (Years)	Diagnostic modality	Diagnosis <sup>a</sup>	Grade of elbow dysplasia <sup>b</sup>	Previous medication	Treatment/medication during study	Treatment/medication changes during study
Ruby (9)	6	Radiography	Bilateral OCD	Grade 1+	Previcox	Previcox	None
Mack (11)	3	Radiography	Bilateral FCP	Grade 1+	Cartrophen	Synaquin	None
Riley (10)	5	Computed Tomography	Bilateral FCP	Grade 1+	Metacam	Metacam, Tramadol	Metacam swapped to Previcox
Floyd (12)	6	Radiography	Bilateral FCP	Grade 1+	Metacam	Metacam	None
Flo (5)	2	Radiography	Bilateral UAP	Grade 1+	NSAID	NSAID	None
Ruby (2)	6	Radiography	Bilateral OCD	Grade 1+	NSAID	NSAID	None

<sup>a</sup>Diagnosis of dogs at the time of referral, OCD = osteochondrosis dissecans, FCP = fragmented medial coronoid process, UAP = ununited anconeal process.

<sup>b</sup>Referral information provided from the veterinarian to the hydrotherapy centres at the time of referral did not routinely contain detail of the grade of elbow dysplasia.

502 Table 2. Baseline kinematic characteristics for both groups and percentage change from baseline after hydrotherapy.

Subject	Group <sup>a</sup>	Baseline ROM <sup>b</sup> (°)	ROM After Hydrotherapy (°)	% Change in ROM	Baseline SL <sup>b</sup> (m)	SL After Hydrotherapy (m)	% Change in SL	Baseline SF <sup>b</sup> (Hz)	SF (Hz) After Hydrotherapy	% Change in SF
1	Control	36.50	37.99	+4.08%	0.225	0.265	+17.70%	0.850	0.900	+5.88%
3	Control	56.69	60.34	+6.44%	0.260	0.265	+1.92%	0.980	0.865	-11.73%
4	Control	51.35	52.79	+2.80%	0.295	0.295	0.00%	0.810	0.825	+1.85%
6	Control	50.58	56.19	+11.09%	0.275	0.275	0.00%	0.855	0.895	+4.68%
7	Control	47.55	52.33	+10.05%	0.260	0.295	+13.46%	0.835	1.030	+23.35%
8	Control	45.01	40.61	-9.78%	0.250	0.285	+14.00%	0.915	0.955	+4.37%
2	ED	18.14	31.64	+74.42%	0.230	0.265	+15.20%	0.825	0.865	+3.30%
5	ED	27.05	37.70	+39.37%	0.230	0.250	+8.70%	0.765	0.815	+6.54%
9	ED	24.35	33.21	+36.38%	0.190	0.205	+7.89%	0.950	0.910	-4.21%
10	ED	29.25	45.14	+54.32%	0.230	0.260	+13.04%	1.020	1.135	+11.27%
11	ED	33.19	49.31	+48.57%	0.230	0.245	+6.52%	1.080	1.100	+1.85%
12	ED	29.41	44.21	+50.32%	0.240	0.265	+10.41%	0.980	1.020	+4.08%

<sup>a</sup> Group of the subject, ED = elbow dysplasia.

<sup>b</sup> Baseline values represent the mean of the right and left limbs of subjects. ROM = range of motion, SL = stride length, SF = stride frequency.

503

504 **Figure Legends**

505 Fig. 1. The change in mean range of motion (degrees) of individual healthy  
506 Labradors (control) and Labradors with elbow dysplasia (elbow) before and after a  
507 session of hydrotherapy. Results for both forelimbs for each dog are displayed.

508 Fig. 2. The change mean stride length (m) of individual healthy Labradors (control)  
509 and Labradors with elbow dysplasia (elbow) before and after a session of  
510 hydrotherapy. Results for both forelimbs for each dog are displayed.

511 Fig. 3. The change in mean stride frequency (Hz) of individual healthy Labradors  
512 (control) and Labradors with elbow dysplasia (elbow) before and after a session of  
513 hydrotherapy. Results for both forelimbs for each dog are displayed.





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